Changing of local wave climate due to ebb delta migration

Ralf Kaiser[1] & Hanz D. Niemeyer[1]

Abstract:

Field measurements highlighted enormous changes in the attenuation of waves propagating from offshore across the ebb delta on the shore face of the East Frisian island of Norderney. The application of mathematical wave model SWAN made evident that the migration of the ebb delta is the cause of these changes. The results are very important for coastal protection measures.

Introduction

The fate of a combined shore face and beach nourishment on the East Frisian island of Norderney (fig. 1) was evaluated. This study was part of the NOURTEC project (Innovative Nourishment Technologies) [Niemeyer et al. 1995] in the framework of the MAST II - Program of the Commission of the European Communities and commissioned to Danish, Dutch and German institutions. Necessarily investigations on local wave climate were incorporated basing as well on field measurements as on mathematical wave models [Niemeyer et al. 1997].

Fig. 1: Location map with stations of directional wave buoy measurements ⊙

[1] Coastal Research Station of the Lower Saxonian Central State Board for Ecology, P.O. Box 1221, 26534 Norderney/East Frisa, Germany

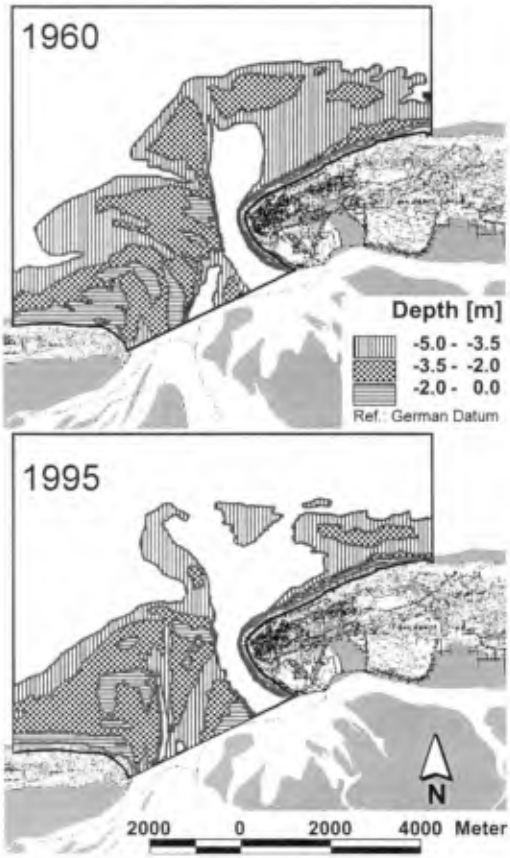

Fig. 2: Change of the higher ebb delta shoals of the Norderneyer Seegat between 1960 and 1995

Field measurements were carried out by directional wave riders (fig. 1); both the well-established second generation model HISWA [Holthuijsen & Booij 1987; Booij & Holthuijsen 1992] and the newly developed third generation model SWAN [Ris 1997; Holthuijsen et. al 1997] have been applied, where the latter is referred to in this paper. The joint application of field measurements and mathematical modeling is regarded as an effective approach for gaining as well reliable data as spatial information on local wave climate.

Field measurements in the offshore area and on the shore face of the island of Norderney highlighted enormous changes in wave damping on the ebb delta of the tidal inlet. In comparison to results from earlier investigations [Niemeyer 1987] waves propagating across the ebb delta are significantly lesser attenuated than before. Even for conditions with no remarkable set-up above mean high tide the shelter effect of the ebb delta for the northwestern shoreface of the island was remarkably reduced.

This change in the shoreface wave climate is a result of the changes of the ebb delta morphology of the Norderneyer Seegat in the last 35 years (fig. 2). Whereas the southwestern part of the system has not changed decisively, the central section has suffered substantial erosion particulary in the upper part. Even the -5m line (with respect to German Datum, which is about mean sea level) which is regarded as the base line of the ebb delta system has two openings, allowing the penetration of higher waves on the shoreface.

In order to get a deeper and more systematic insight into background of these processes runs with the mathematical wave model SWAN [RIS et al. 1995] have been carried out for four distinct morphological situations of the area seaward of the tidal inlet and the northwestern shore of the island of Norderney: the bathymetries of 1960, 1975, 1990 and 1995 were used as a basis for model topography.

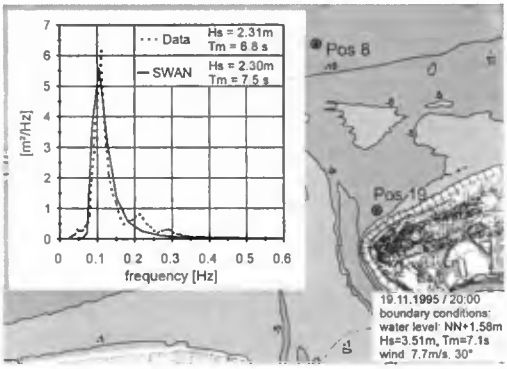

Fig. 3: Comparison of the measured and calculated energy spectrum at Pos. 19

Verification and Sensitivity study

The verification was carried out for several distinct water levels and offshore wave boundary conditions. The results for Pos. 19 are generally good und sometimes excellent (fig. 3). It became apparent that the fitting of model results and measurements or the northwestern shoreface of Norderney improves, if the TRIAD option in SWAN is switched off. With this setting SWAN generally gives a good representation of the spectrum with a slight underprediction of the significant wave height and slight overprediction of the mean wave period at Pos. 19. For other positions in the inner part of the inlet the incorparation of the TRIAD interaction gives the better results. Since the major interest of this study is focussed in wave climate on the shoreface of the north western beach, in all runs discussed for this case the TRIAD interaction have been switched off.

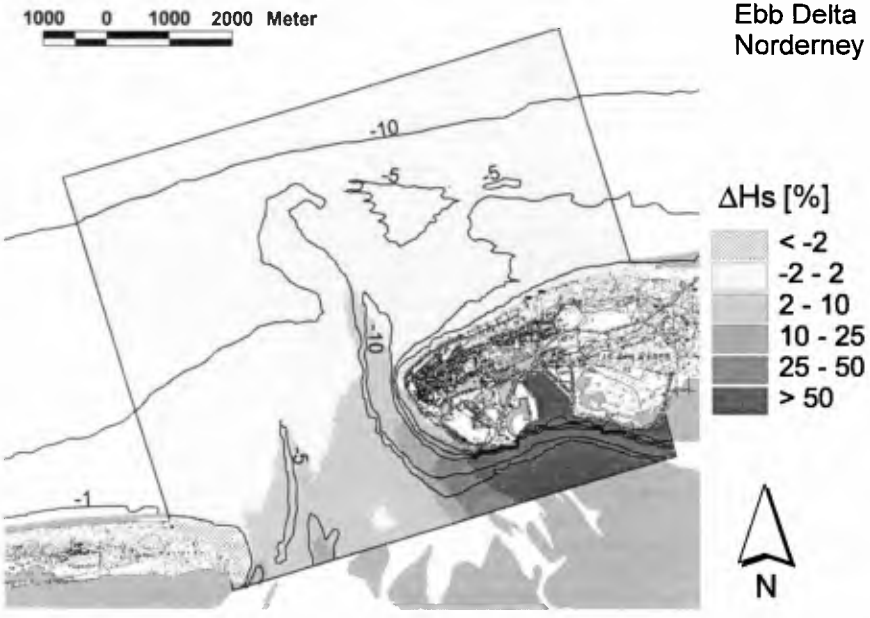

Fig. 4: Increase of significant wave heights due to uniform local wind; boundary conditions: Water level: MSL+1.58m; Hs=3.51m, Tm=7.1s; Wind: 7.7 m/s, 30°

Checking the neccessity of a local varying wind field a crude estimation can be done in comparing model results with a uniform wind field to a run with out any wind (fig. 4). The difference between wave heights for situations with no wind and uniform wind are smaller than 2% on the shoreface. Therefore it is not necessary to imply here a local varying wind field. Further inwards in the inlet and especially behind the island the influence of the local wind becomes substantial, so that there might be the demand for a local varying wind field.

It became also significantly evident that the application of the third generation model SWAN delivers results matching much better the prototype data than with the second generation model HISWA achivable (Niemeyer & Kaiser 1998). Furthermore SWAN delivers full spectral information.

Morphological changes of the ebb delta

The comparison of the topography for the distinct four situations makes significant morphological changes evident (fig. 5): Whereas the ebb delta is becoming even more pronounced after 1960 with a climax in 1975 the later surveys in 1990 and 1995 highlight a reduction of the shallows with heights above German datum NN - 5 m accompanied by a migration and seaward directed deepening of the main inlet channel between 1990 and 1995: Both morphological changes enhance onshore wave penetration in direction of the island's northwestern shores.

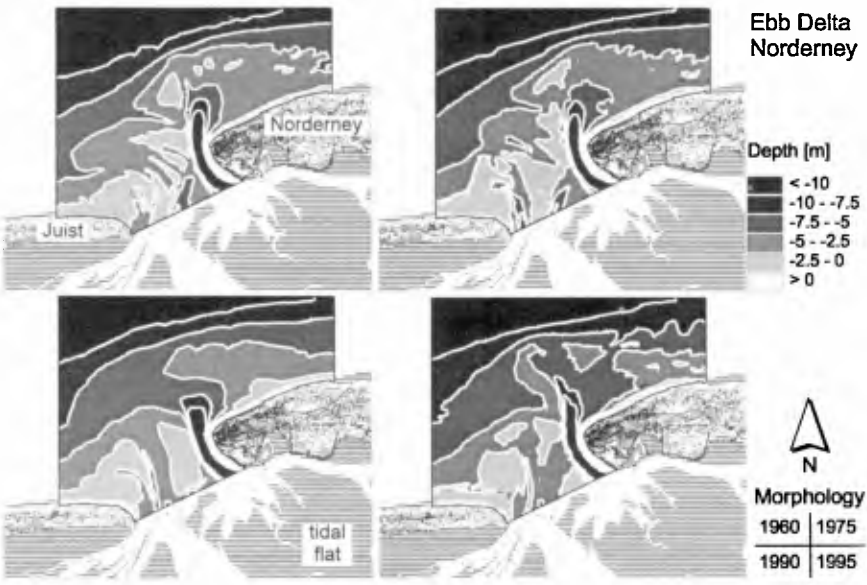

Fig. 5: Bathymetry of the seaward area of the western part of the island of Norderney with the ebb delta in 1960, 1975, 1990 and 1995 (depths related to German datum NN= MSL)

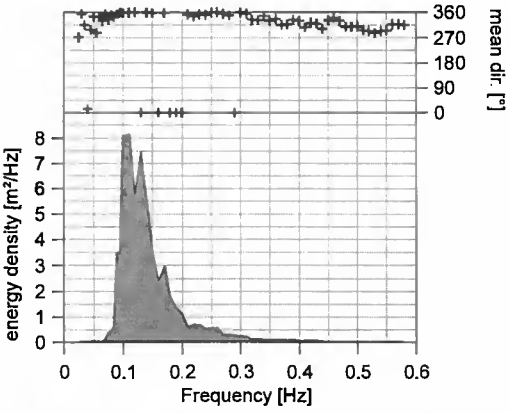

Fig. 6: Measured spectrum at the seeaward boundary at 17.11.95, 04:58

Model results

ordinary tide

The models have been run for distinct water levels and offshore wave parameters as seaward boundary conditions. Exemplary for an ordinary tide the results of a run with the following boundary conditions are highlighted here which have been gained from field measurements: Set-up of about 0,3m above MHWL (in sum equivalent to a water level of NN + 1,42 m) and an offshore wave field (fig. 6) with a significant wave height Hs = 2,98 m and a peak period Tp = 6,4 s. Wind comes from 344° with a velocity of 8.2 m/s. The model runs with SWAN confirm the impression already gained from field measurements with respect to the penetration of

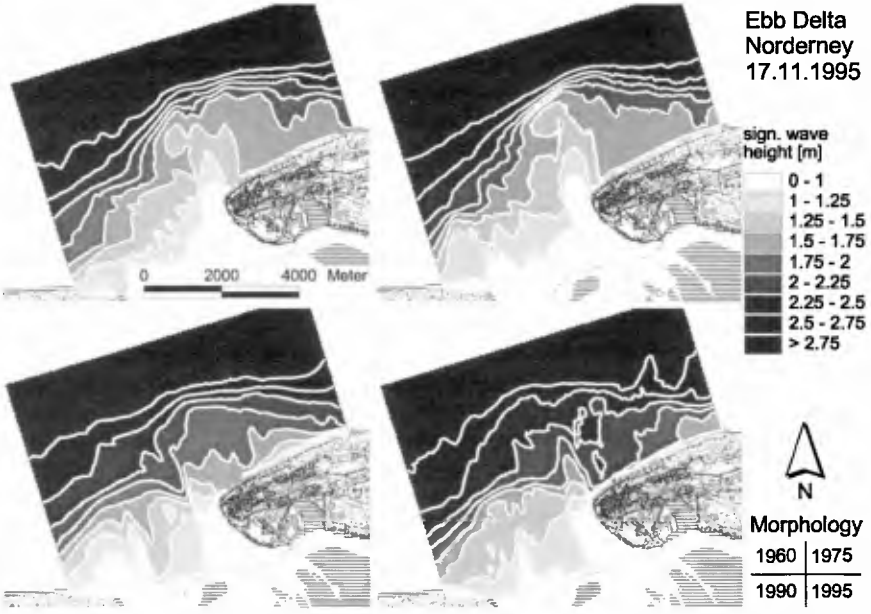

Fig. 7: Significant wave heights in the offshore area, in the tidal inlet Norderneyer Seegat and on the northwestern shoreface of the island of Norderney in 1960, 1975, 1990 and 1995. Boundary conditions: Water level: MSL+1.42m; Wind: 8.2m/s, 344°

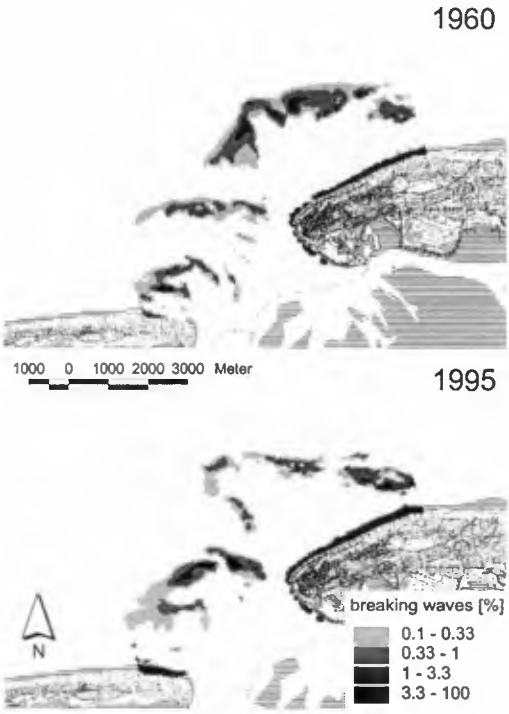

Fig. 8: Percentage of breaking waves in the 'normal' situation of 10.01.95 calculated with the morphology of 1960 and 1995

higher waves onto the northwestern shoreface of the island of Norderney (fig. 7): For the situations of 1960 and 1975 no significant changes occur. But already for the topography of 1990 higher waves with 1,75 m < Hs < 2,00 m propagate across the ebb delta though not appearing nearshore. For the topography of 1995 waves with heights with this order of magnitude occur on a large part of the shoreface. This increase in nearshore wave energy has the same trend as prototype data; the measured wave heights on the shoreface are even slightly higher than those being computed with the model for the same offshore conditions.

The comparison between the portion of breaking waves for the topography of 1960 and 1995 highlights the change in wave transformation over the bars of the ebb delta (fig. 8). In 1960 there is a broad breaker zone at the offshore edge of the eastern ebb delta and two successive breaker systems in the western part. In 1995 there is much lesser wave breaking on the shoals of the ebb delta in its central and eastern part. Also the formerly existing two breaker zones in the western part have changed into a more pronounced single one due to the higher shoals of 1995 in that area.

In order to make the effect of this change in local wave climate more evident for the dynamics on the northwestern shore face and beaches of the island of Norderney the computed significant wave heights for all four morphological situations are compared at 17 selected points at the edge of shore face and beach parallel to the island's northwestern shore (fig. 9). For the situations of 1960 and 1975 there are no remarkable changes in wave climate. The significant wave heights are of the same order of magnitude on the whole stretch of the northwestern shore face. In 1990 there is an increase of wave heights up to 40%, particularly in the stretch between the reference points 3 and 5 but they decrease further downdrift and become even smaller in the eastern part of the study area. In 1995 wave height have additionally increased in all places downdrift of point 4 (fig. 9).

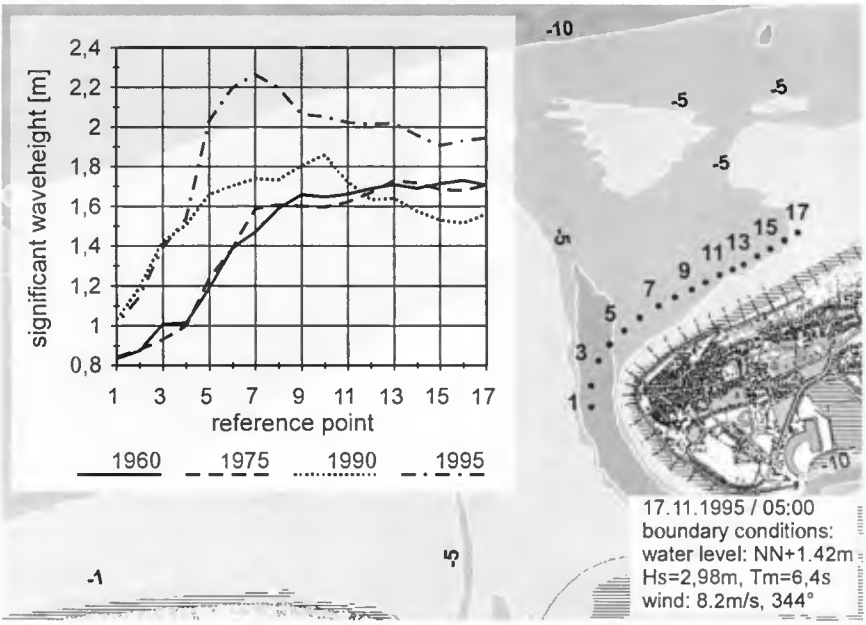

Fig.9: Significant wave heights at the edge of shoreface and beach parallel to the northwestern shore of the island of Norderney according to the bathymetry in 1960, 1975, 1990 and 1995 (computed with SWAN)

The difference between the four morphological situations absolutely has to be considered in comparing the effectiveness of different beach nourishments in the last 35 years. The unfavorable boundary conditions of 1995 compared to the previous situations are another indication for the superior effectiveness of the combined nourishment executed in the framework of NOURTEC project.

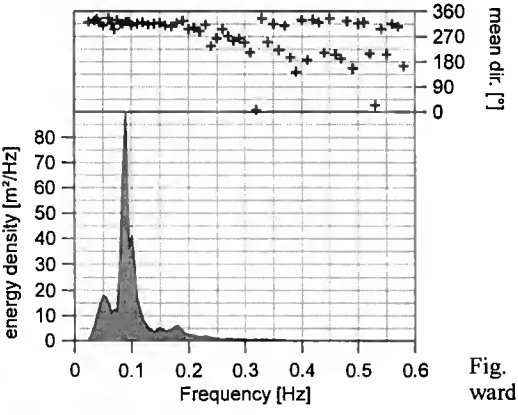

Fig. 10: Measured spectrum at the seaward boundary at 10.011.95, 04:56

storm condition

Explanatory for wave conditions during a storm are the results of a run with the following boundary conditions which have been gained from field measurements in January 1995: Set-up of about 2,3m above MHWL (in sum equivalent to a water level of NN + 3.46 m) and an offshore wave field (fig. 10) with a

significant wave height Hs = 6.41 m and a peak period Tp = 11.1 s. Wind direction is 295° with a velocity of 22 m/s. As well as for the results for the ordinary tidal conditions here occur also only small differences between the local wave heights calculated for the morphologies of 1960 and 1975 (fig. 11). Nevertheless, in 1990 higher waves in the order of 2.5 - 2.75 m arrive at the north western shoreface of the island. Also, a penetration of higher waves into the inlet is evident. In 1995 the erosion in the central part of the ebb delta has reduced the effectiveness of the ebb delta remarkably to act like a breakwater. Wave attenuation is there less pronounced leading to higher energy dissipation on the shoreface with a more pronounced breaker zone.

Also fro the storm conditions a quantitative comparison has been carried out for the the significant wave heights at 17 selected points at the edge of shoreface and beach parallel to the island's northwestern shore (fig. 12) on the basis of the results of the mathematical model. As well as for the ordinary tide condition the situations of 1960 and 1975 show no remarkable changes in wave climate for storm conditions. The significant wave heights are of the same order of magnitude on the whole stretch of the northwestern shore face. In 1990 there is an increase of wave heights starting at reference point 2 reaching its maximum at point 9 with about 15%, decreasing further down drift and become even smaller in the eastern part of the study area. In 1995 the wave heights are nearly in the same order of

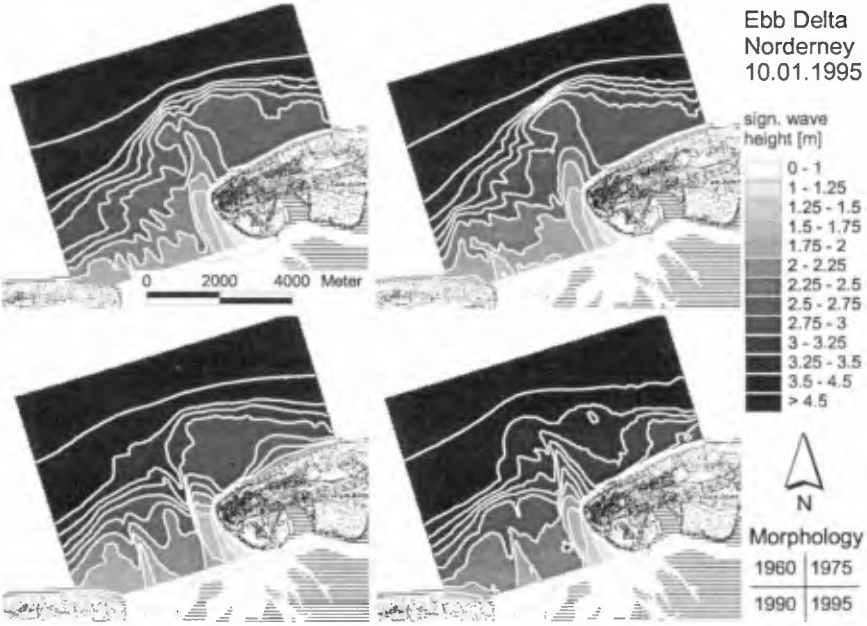

Fig. 11: Significant wave heights in the offshore area, in the tidal inlet Norderneyer Seegat and on the northwestern shoreface of the island of Norderney in 1960, 1975, 1990 and 1995. Boundary conditions: Water level: MSL+3.46m; Wind: 22m/s, 295°

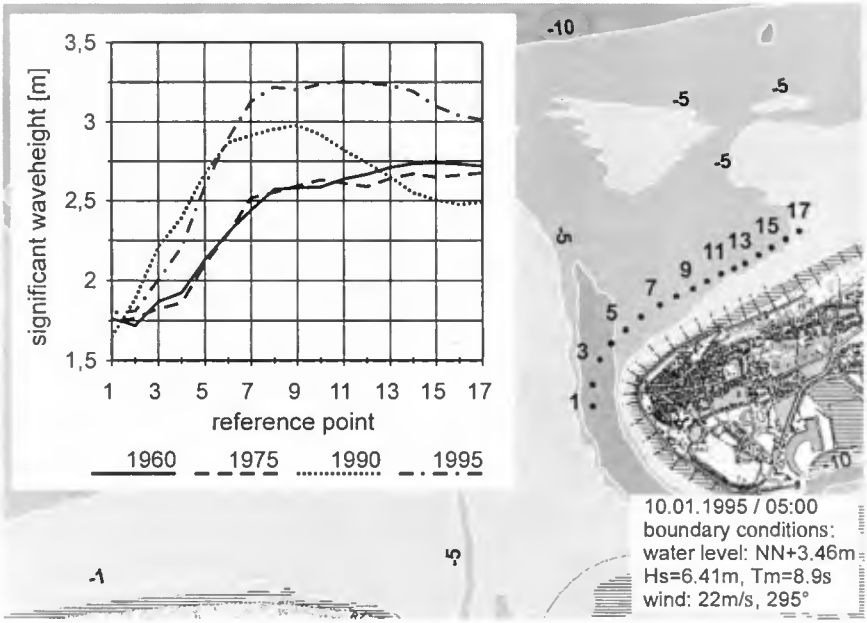

Fig. 12: Significant wave heights at the edge of shoreface and beach parallel to the northwestern shore of the island of Norderney according to the bathymetry in 1960, 1975, 1990 and 1995 (storm condition, computed with SWAN)

magnitude as in 1990 up to reference point 6 but then further increasing down drift and remaining on a high level up to the end of the investigation area. The maximum increase in wave height is about 20% between the reference points 8 and 10 comparing the 1960 and 1995-situation.

Conclusivly the relation of wave heights on the shoreface and the offshore wave boundary condition has been calculated both for the ordinary tide and the storm situation (fig. 13). On the one hand the results hightlight the presently decreased capability of the ebb delta to reduce the offshore wave energy. For ordinary tidal high water levels even waves with a significant height of about 3 m reach the shoreface only reduced by 25 % (reference point 7). In the other case the wave heights (Hs = 6.4m at the offshore boundary) during a storm event with a set-up above MHWL of about 2.3m were reduced at least by 50%. These figures are remarakably smaller than for the modified situations of earlier states

Comparing the morphological states of 1960 and 1995 the consequences of the ebb delta migration can be differentiated for different boundary conditions: For the storm condition there is an increase at the shoreface in the maximum from 40% to 50% of the offshore wave height. This increase starts slowly at the western edge and is then nearly the same downdrift of point 6. For the ordinary tide and the morphology of 1960 the relation of foreshore to offshore wave height starts at nearly the same value as for the storm condition,

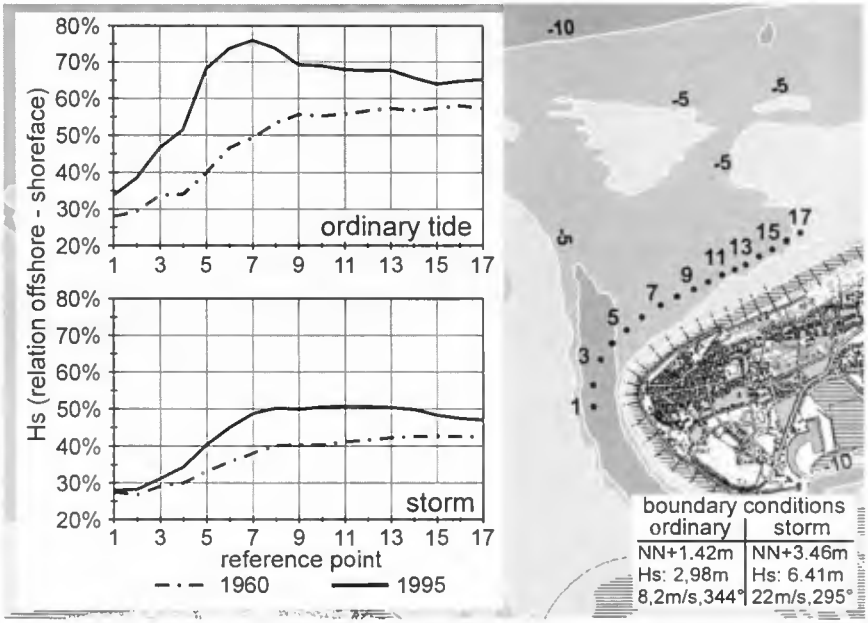

Fig: 13: Relation of the significant waveheight offshore of the ebb delta and on the shoreface for ordinary tide conditions and during a storm event calculated with the bathymetries of 1960 and 1995

increasing further down drift and reaching it maximum im point 9 with about 58%. The situation of 1995 is in contrast to that much faster increasing with a distinctive maximum between the points 4 and 9. As a consequence the foreshore wave height in 1995 is at point 7 about 75% of the offshore wave height compared to only 50% in 1960. This is also reflected in the higher erosion rates in that stretch (Niemeyer et al. 1997).

Conclusion

Wave climate studies have been carried out for distinct bathymetries of ebb delta, shoreface and tidal inlet by application of the mathematical wave model SWAN. It has proved to be a suitable tool for the reproduction of the wave climate in an environment with heterogenous morphological pattern. The results of the verification runs show a good agreement for the wave parameters in the whole study area and the same for the spectrum on the shoreface. It is important to have sufficient areal wave data for the verification in different stages of the transformation of the wave field. The application of the third generation model SWAN leads to an improved fitting of model results and field data in comparison to the earlier used second generation model HISWA.

The changes of the ebb delta morphology of the Norderneyer Seegat within the last 35 years caused a higher impact of waves on the north western shoreface. Consequently both beach erosion and losses of nourished material increase remarkably.

For ordinary tides changes of wave climate on the shoreface are relatively higher than for storm conditions.

Acknowledgement

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